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Plasma diagnostics in high-power impulse magnetron sputtering of compound NbC target

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1 Introduction

Transition metal carbides have attracted a lot of attention in recent years due to their possible use in protective coatings, catalytic materials, and electronics. They have also been explored as a material with excellent electrical conductivity, mechanical strength, and chemical and thermal stability. Thin NbC films have been deposited from a single compound target using high-power impulse magnetron sputtering (HiPIMS), which uses short duty cycles (a few percent) and high pulse powers to achieve more ionization than traditional DC magnetron sputtering for the same average power. According to recent research by Bahr et al. (2022), by adjusting the power density of the pulse, it is possible to control the film composition (Nb/C ratio), microstructure, and, subsequently, mechanical properties.

The main focus of this study will be on explaining the compositional evolution from C-rich films to stoichiometric NbC films that was seen in response to an increase in pulse power density. The transport of sputtered Nb and C atoms towards the substrate is influenced by several processes, including the sputtering rate and angular distribution, scattering off the process gas atoms, ionization in the high-density plasma, and return of ions onto the target or loss of them to chamber walls. These processes are expected to occur differently for Nb and C due to the two elements' different atomic weights and ionization potentials. The sputtering of compound targets by HiPIMS discharges is not fully understood yet.

In this study, the effects of the aforementioned plasma processes on the transport of atoms and ions in the discharge and, eventually, on the Nb/C ratio in the films were investigated in different pulse power densities and distances from the target, using time-averaged plasma diagnostic techniques. Optical emission spectroscopy (OES) was used to measure the ratios of sputtered species neutrals and ions at various discharge positions, and mass spectroscopy was used to measure Nb^+ and C^+ fluxes at the substrate position.

2 Results and discussion

Fig. 1 shows the total fluxes denoted $(C+C^+)_{dep}$ and $(Nb+Nb^+)_{dep}$, which are determined from the composition and deposition rate of films, the ion fluxes denoted Nb^+ and C^+ that are determined by mass spectroscopy, and the neutral fluxes denoted Nb and C, which are calculated from the ion fluxes and the dependence of C^+/C and Nb^+/Nb ratios on the pulse power density determined by Optical Emission Spectroscopy (OES).

Anders (2011) showed that in HiPIMS, higher ionization efficiencies can be attained by enhancing the target power density, so the atoms are more frequently ionized due to the higher electron density, resulting in an increased ion-to-neutral ratio. As shown in Fig. 1, by increasing pulse power density, the density of Nb^+ and C^+ grows at the expense of Nb and C. Due to lower ionization energy and a larger ionization cross-section of Nb compared to C atoms, it is

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discovered that the density of Nb ions in comparison to C ions is substantial even for low power densities.

The decrease in C flux observed across the range of studied pulse power densities surpasses the decrease in Nb flux. These findings align with the deposition fluxes obtained from the deposited films. The fluxes indicate the deposition of C-rich films at the lowest pulse power density, which is consistent with the experimental results. Conversely, at the highest pulse power density, the fluxes suggest the deposition of Nb-rich films, which contradicts the experimental observation where the films were close to stoichiometric (The Nb/C ratio varied from 0.6 to 0.95 by increasing pulse power density).

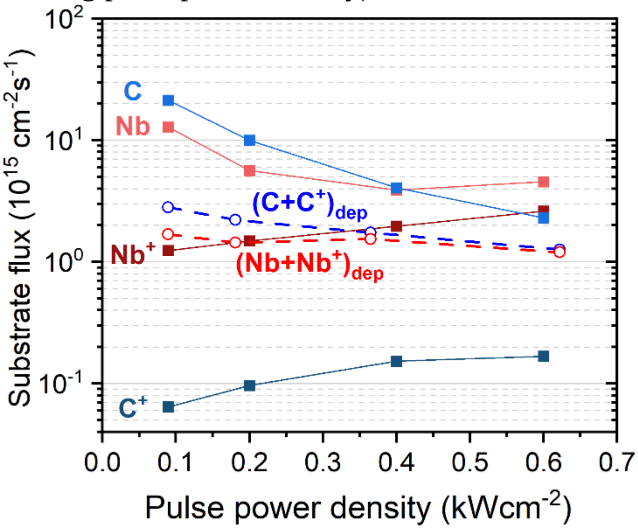

Figure 1: The fluxes of C and Nb species on the substrate determined from the composition of deposited films and plasma diagnostics.

References

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